



Small Satellite Aerocapture for Increased Mass Delivered to Venus and Beyond

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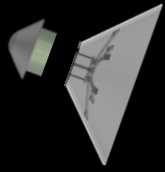
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University of Colorado Boulder

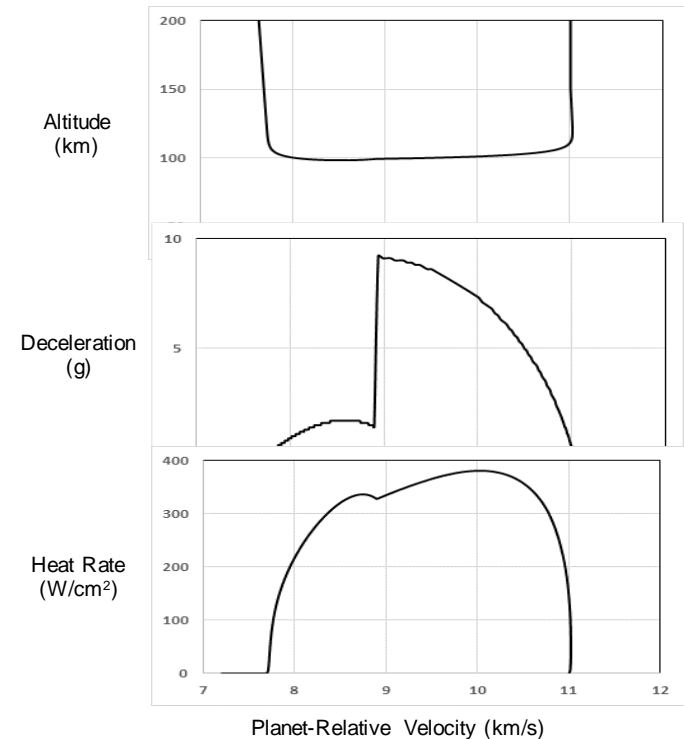
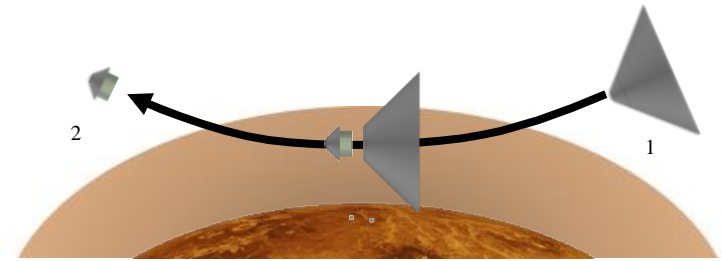
June 14, 2018



Overview

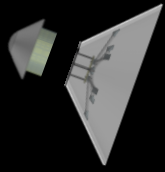


- A multi-organizational team is developing an aerocapture system for Small Satellites
 - Currently in year 1 of a 2-year effort
- Utilize drag modulation flight control to mitigate atmospheric & navigation uncertainties
 - Initially studied by Putnam and Braun in “Drag Modulation Flight Control System Options for Planetary Aerocapture”
 - Simplest form is the single event jettison
 - Ballistic coefficient ratio (β_2/β_1) provides control authority
- Study addresses key tall tent pole challenges
 1. Orbit targeting accuracy
 2. Thermal protection systems
 3. Stability before, during, and after jettison event
- Technology development has so far been “mission-agnostic”
 - Pursue a notional flight system design and target orbit to demonstrate existence proof
 - Design and tools can be custom-tailored for a range of possible science missions



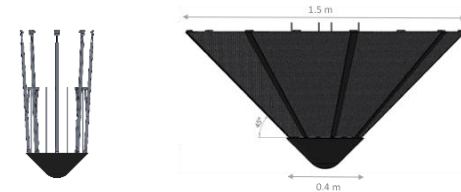


Mission Applicability

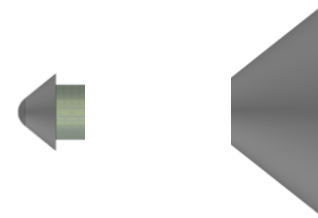


- Potential Destinations:
 - Venus
 - Earth
 - Mars
 - Titan
 - Ice Giants
- Vehicle Options:
 - Mechanical deployable drag skirt
 - Rigid drag skirt
- Delivery Schemes:
 - Dedicated launch & cruise
 - Delivery by host spacecraft

Mechanical deployable
drag skirt

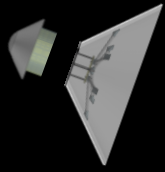


Rigid drag skirt





Mission Applicability



- Potential Destinations:

- Venus

- Earth

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- Titan

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- Vehicle Options:

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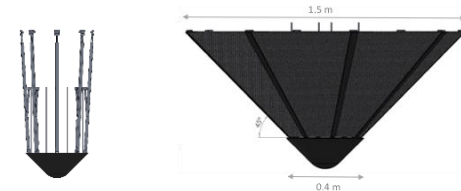
- Rigid drag skirt

- Delivery Schemes:

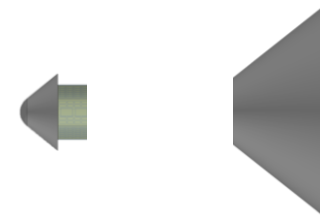
- Dedicated launch & cruise

- Delivery by host spacecraft

Mechanical deployable
drag skirt



Rigid drag skirt

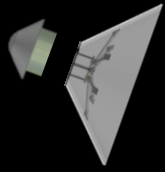


Initial Focus:

Chose Venus to bound the technology's capability. Can scale to “easier” destinations.
Chose rigid drag skirt and host spacecraft delivery to minimize system complexity.

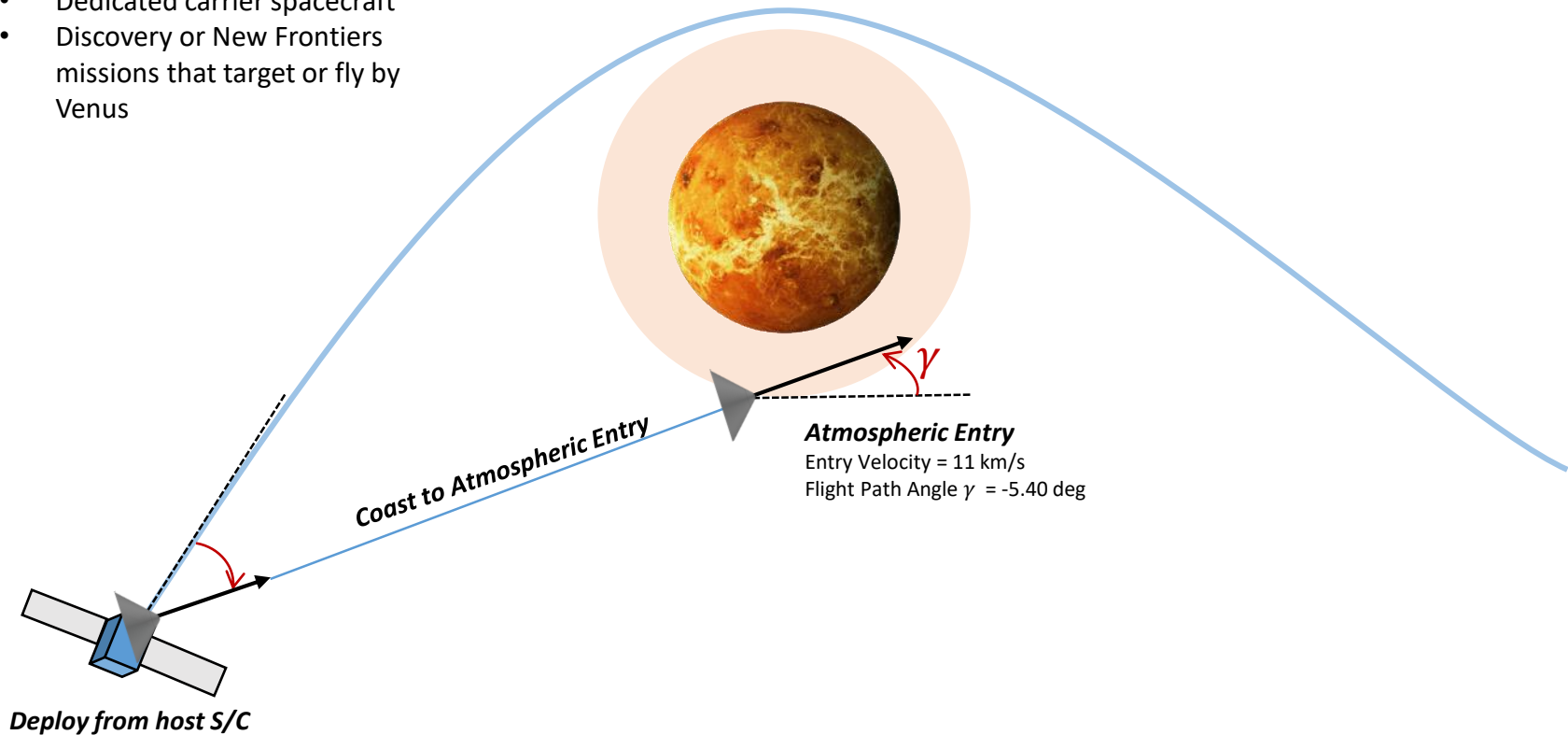


ConOps: Exo-Atmospheric



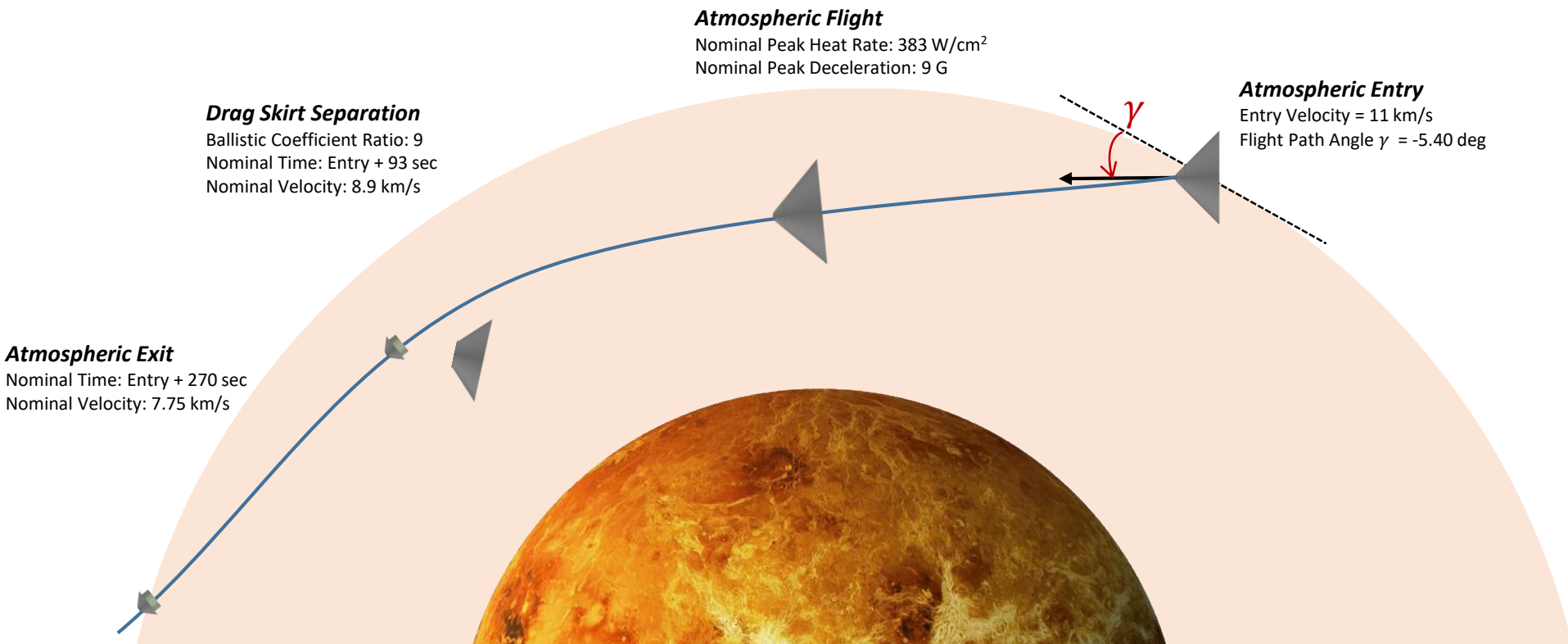
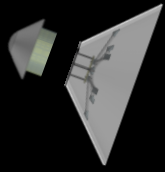
Potential Hosts:

- Dedicated carrier spacecraft
- Discovery or New Frontiers missions that target or fly by Venus



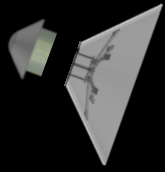


ConOps: Atmospheric



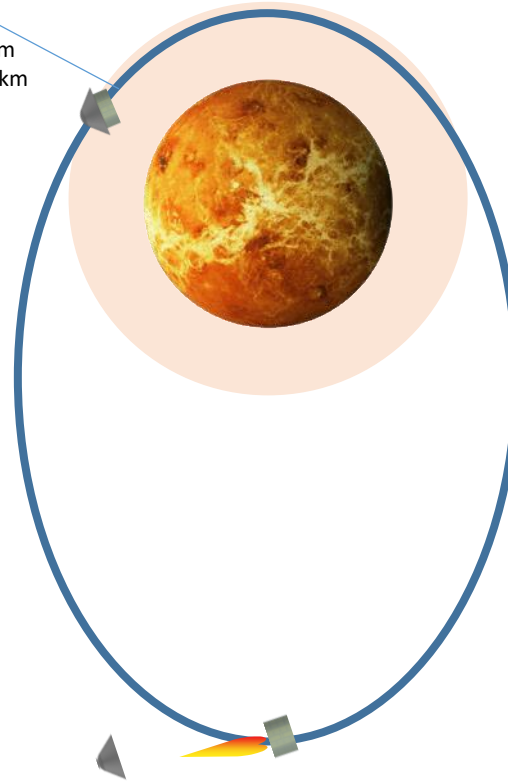


ConOps: Post-Aerocapture



Initial Orbit

Periapsis: 100 km
Apoapsis: 2000 km
Period: 1.83 hr

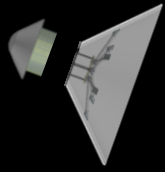


Drop Heat Shield + Periapsis Raise Maneuver

Nominal Time: Atm. Exit + $\frac{1}{2}$ Period
Trigger: Timer



ConOps: Post-Aerocapture

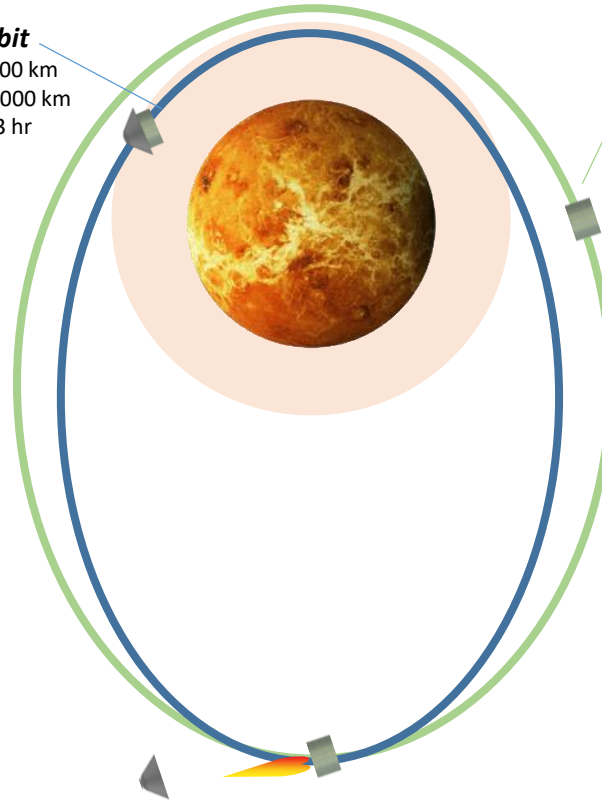


Initial Orbit

Periapsis: 100 km
Apoapsis: 2000 km
Period: 1.83 hr

Final Orbit

Periapsis: 200 km
Apoapsis: 2000 km
Period: 1.85 hr

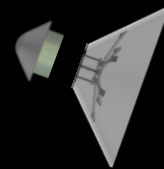


Drop Heat Shield + Periapsis Raise Maneuver

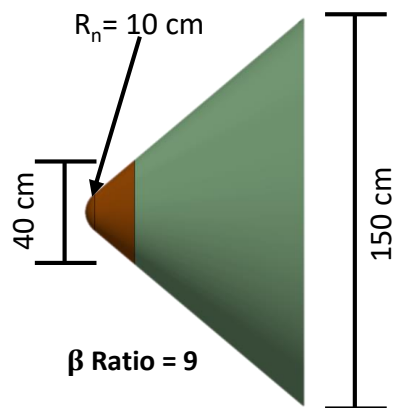
Nominal Time: Atm. Exit + $\frac{1}{2}$ Period
Trigger: Timer



Representative Flight System

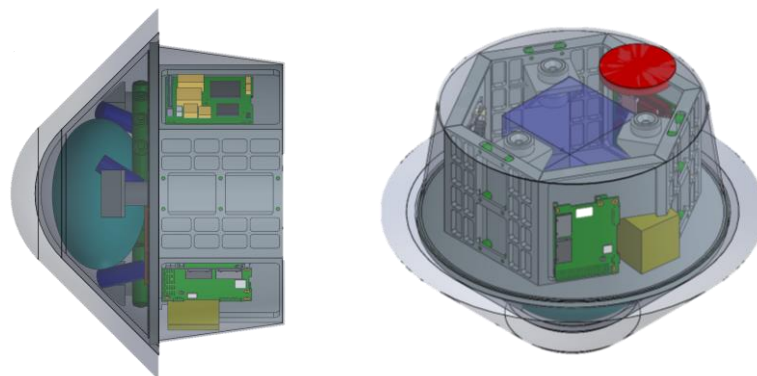


Pre-Jettison Configuration



- Science Payload
 - ~1U available volume
- Telecom (~2.5 kbps to 70m DSN)
 - IRIS X-Band Radio
 - X-Band Patch Antenna
 - X-Band Circular Patch Array HGA
- ACS (~10 arcsec pointing accuracy)
 - BCT Star Tracker, Sun Sensors (x4), and Control Electronics
 - BCT Reaction Wheels (x3)
 - Sensor IMU
- C&DH
 - JPL Sphinx Board
 - Pyro Control Board

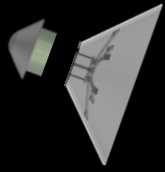
Delivered Flight System



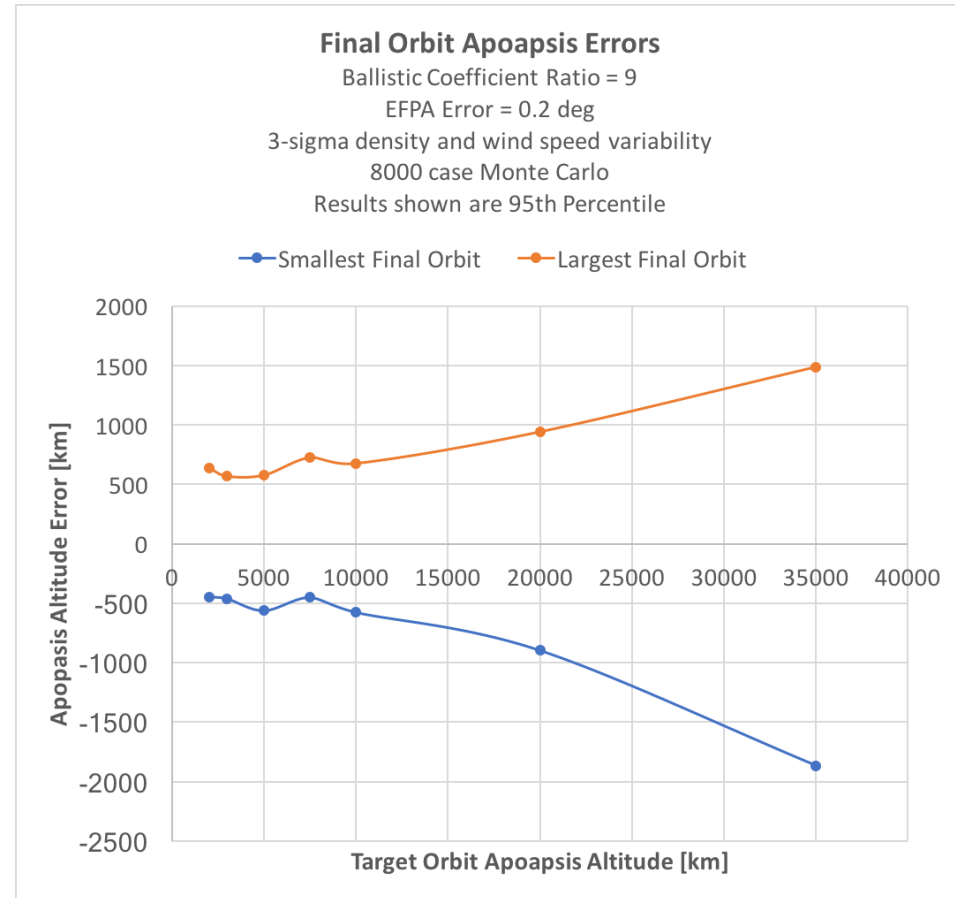
- Thermal
 - Kapton Film Heaters
 - MLI
- Power (~25 W with body mounted solar cells)
 - Solar Arrays
 - Clyde Space EPS
 - 18650 Li-ion batteries (x13) (~220 Wh)
- Propulsion (~70 m/s delta-V)
 - 0.5 N Monoprop Thrusters (x4)
- Mechanical
 - Structure, TPS, Rails, Rollers, Separation Hardware



Orbit Delivery Accuracy

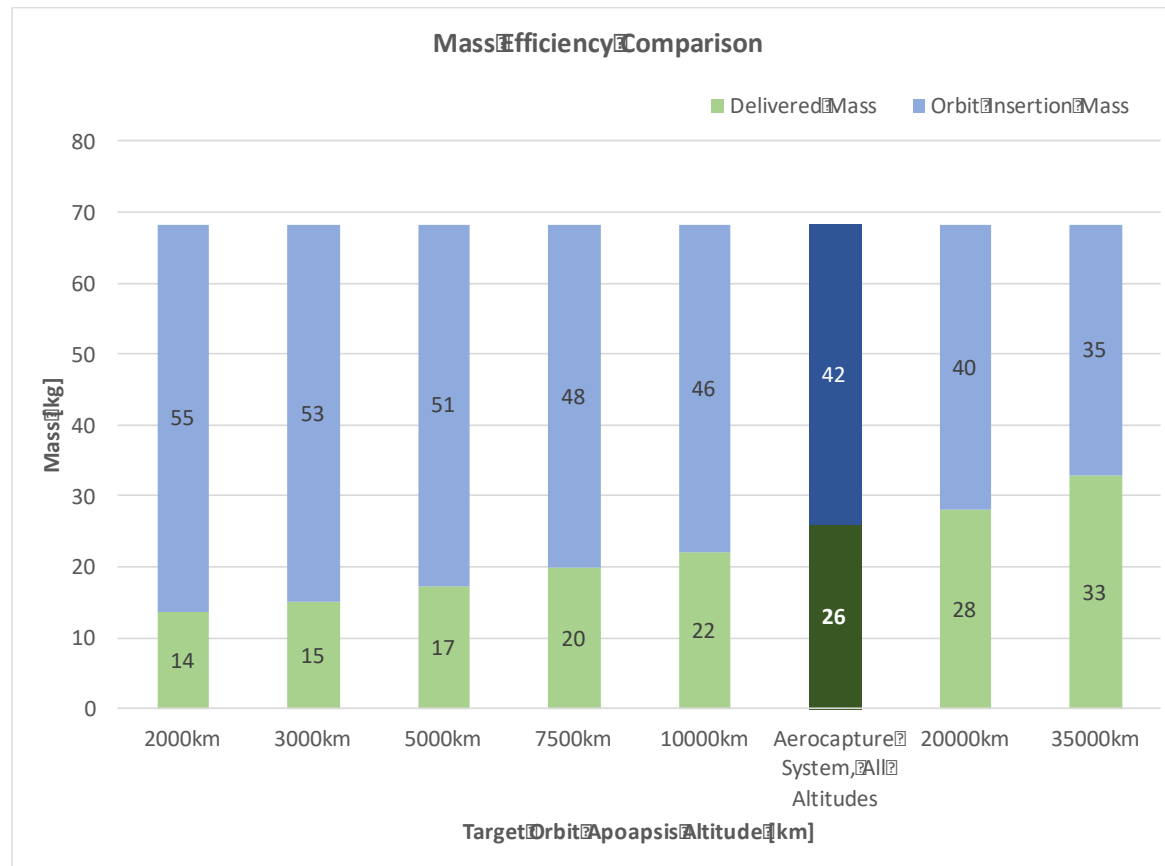
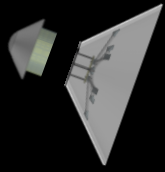


- 3DOF Monte Carlo runs in JPL's DSENDS trajectory tool used to assess orbit targeting accuracy
 - VenusGRAM atmospheric model with 3-sigma variability in density and wind speeds
- Options for improving orbit targeting accuracy are under investigation
 - Reduce EFPA error
 - Increase ballistic coefficient ratio
 - Improve G&C algorithm driving drag skirt separation





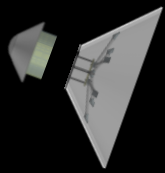
Mass Efficiency Comparison



- The aerocapture-based orbit insertion system can deliver up to 85% more useful mass to orbit than a propulsive system, depending on target orbit



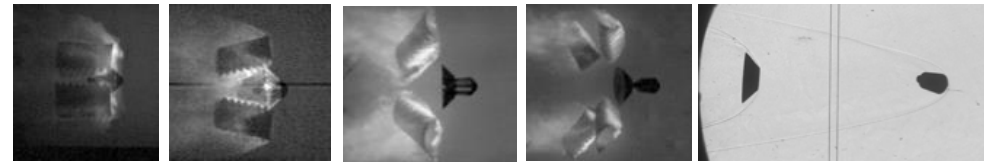
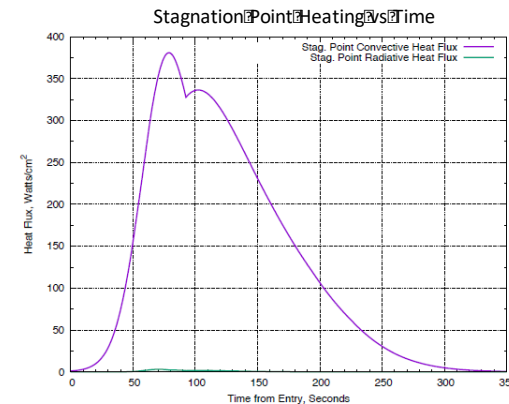
Other Activities



NASA Ames

- Aerothermal analysis
- TPS sizing
- CFD simulations
- Ballistic range test development

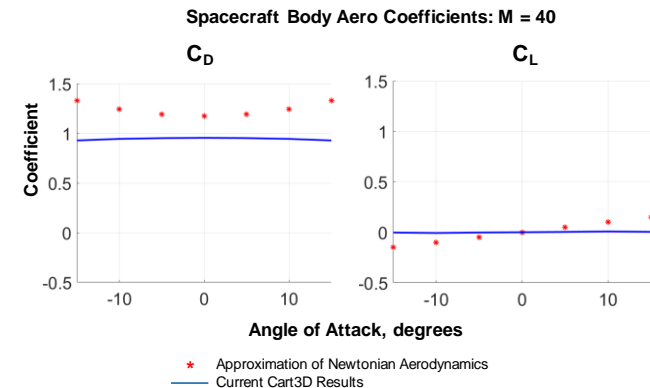
See Robin Beck's presentation "Studies in support of Venus aerocapture utilizing drag modulation" for more information



CU Boulder

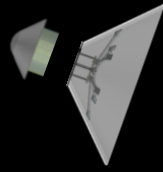
- G&C algorithm development
- CFD simulations

See Michael Werner's presentation "Dynamic propagation of discrete-event drag modulation for Venus aerocapture" for more information





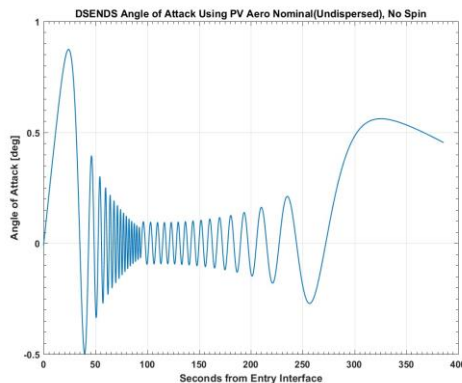
Conclusions and Future Work



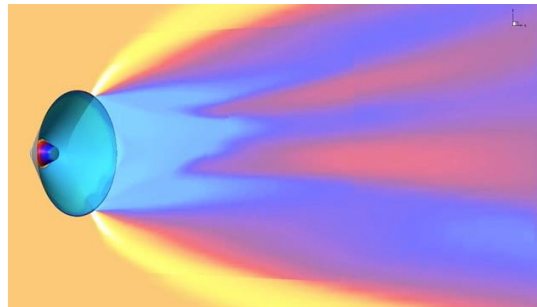
This initiative addresses the following key challenges for drag modulation aerocapture at Venus:

1. Orbit targeting accuracy
 - 3DOF Monte Carlo simulations of the maneuver
 - ✓ G&C algorithm improvements (Work to Go)
 2. Thermal protection systems
 - Preliminary aerothermal assessment and TPS design
 - ✓ CFD detailed aerothermal assessment (In Progress)
 3. Stability before, during, and after jettison event
 - Preliminary 6 degree-of-freedom DSENGS simulations
 - ✓ CFD analysis of dynamics of drag skirt separation (In Progress)
 - CFD aerodynamic database generation (Work to Go)
 - Ballistic range testing (Work to Go)
- To improve mission accommodation options, investigating an ADEPT-based mechanical deployable drag skirt option

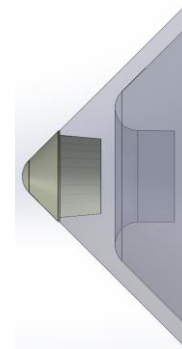
6DOF Trajectory Simulation

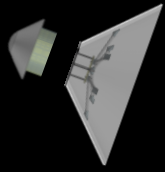


CFD Separation Analysis



Ballistic Range Model Design

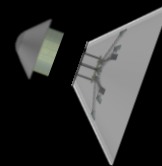




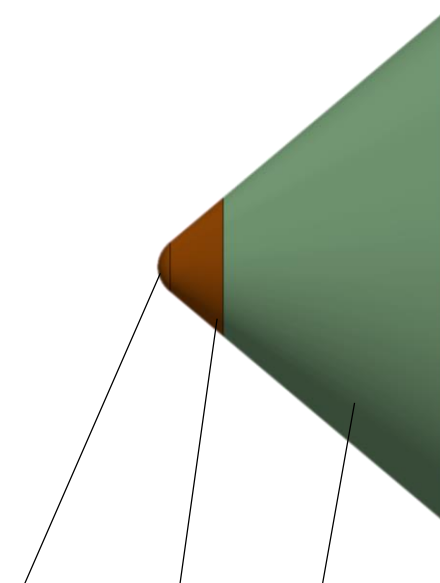
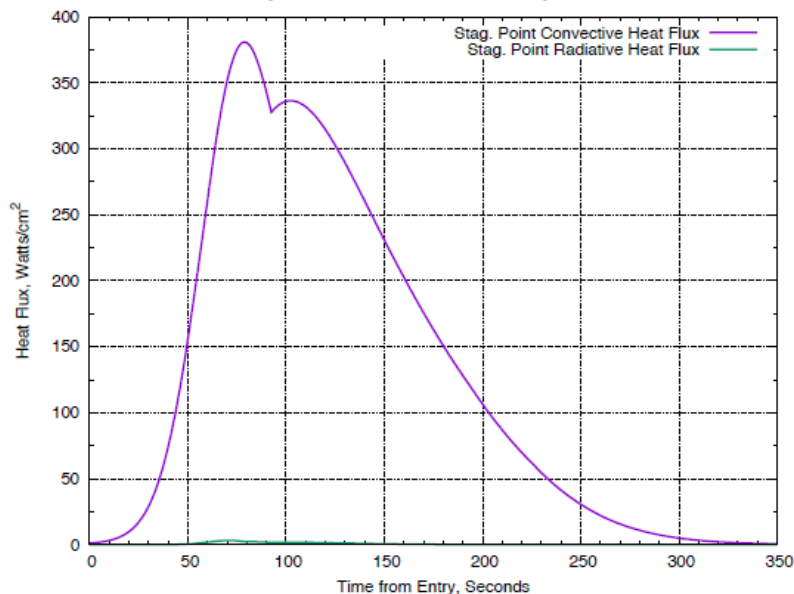
Thank you!



Aerothermal & TPS



Stagnation Point Heating vs Time



	Nose	Flank (est)	Skirt (est)
Peak Heatflux (W/cm2)	383.3	191.65	191.65
Peak Heatload (J/cm2)	45179	22590	3840
Peak Pressure (Pa)	8800	4400	3650
C-PICA thickness (cm)	2.58	1.88	0.72
PICA thickness (cm)	4.125	3.51	1.11
C-PICA mass (kg)	0.13	0.80	4.56
PICA mass (kg)	0.20	1.45	6.83

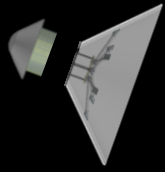
Total heat-shield only TPS mass for pre-and post-jettisoned bodies combined:

C-PICA 5.49 kg (**Un-margined** engineering estimate)

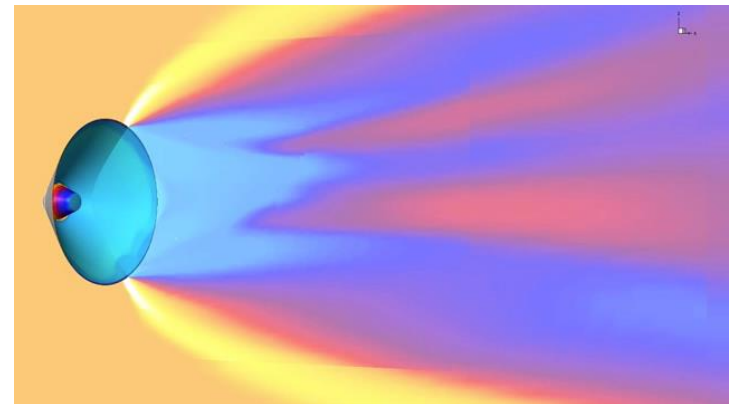
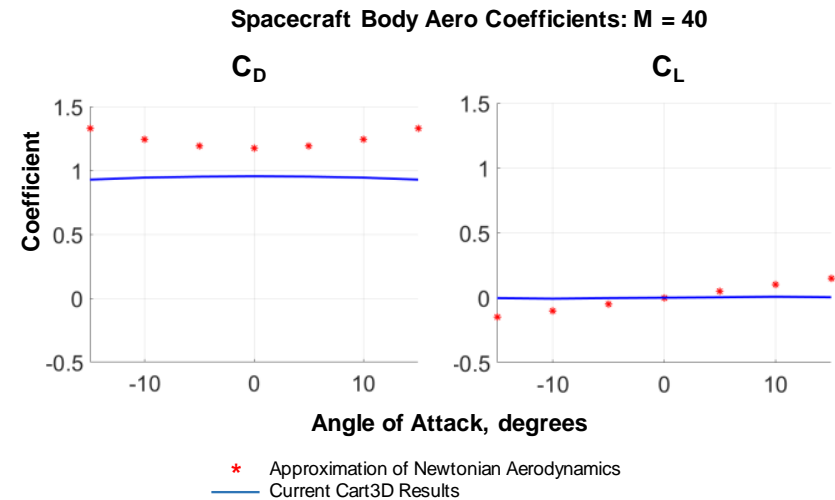
PICA 8.48 kg (**Un-margined** engineering estimate)



Aerodynamics

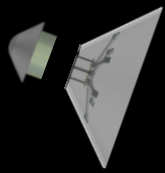


- CFD simulation development in Cart3D underway at CU Boulder
 - Currently troubleshooting coefficient errors vs. Newtonian aerodynamics
- Objectives
 - Analyze forces & moments during separation event
 - Generate 6DOF aerodynamic database



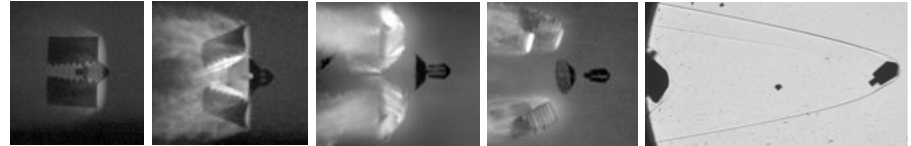


Ballistic Range Testing

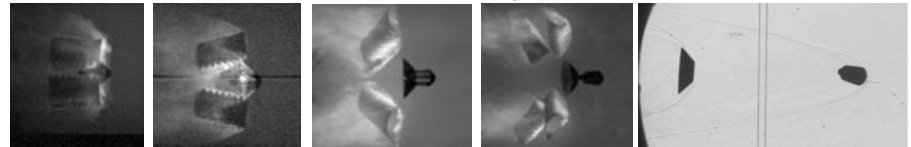


- Ballistic range at NASA Ames has been modified to image the separation event
- Several exploratory test shots have been performed this year
- Ballistic range test articles based on final study design to be fabricated by end of FY18
- Multiple ballistic range shots planned for FY19

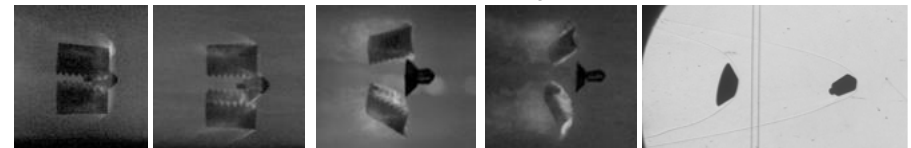
Shot 2798: $P_{\infty} = 114$ Torr (0.15 atm), $\rho_{\infty} = 0.181$ kg/m³



Shot 2799: $P_{\infty} = 76$ Torr (0.1 atm), $\rho_{\infty} = 0.121$ kg/m³



Shot 2800: $P_{\infty} = 50$ Torr (0.067 atm), $\rho_{\infty} = 0.079$ kg/m³



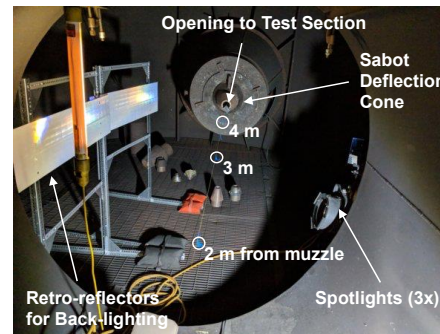
1 m

2 m

3 m

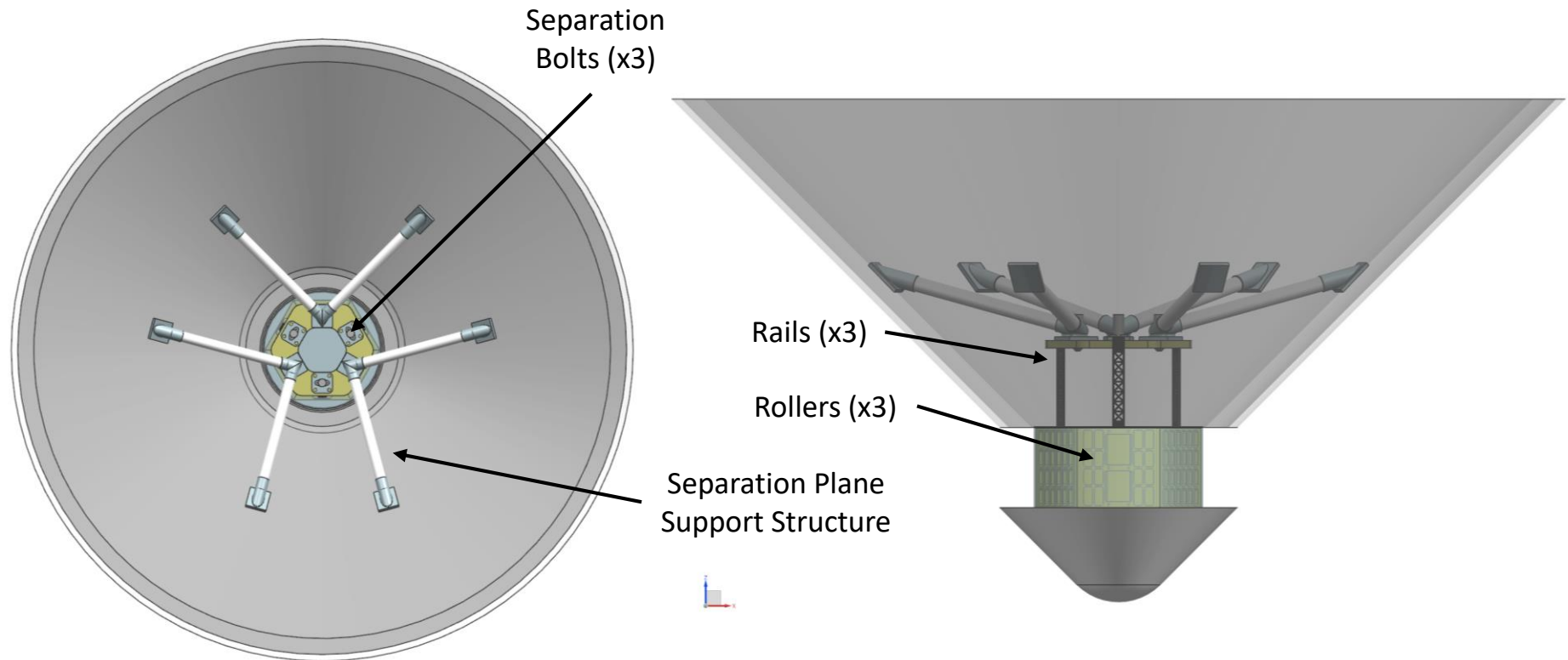
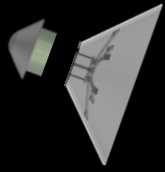
4 m*

10.13 m from Muzzle





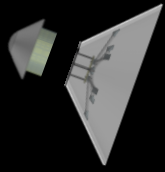
Aeroshell Mechanical Design



- 3 separation bolts fire when triggered by the flight computer
- MSL-inspired rail & roller design reduces re-contact risk during drag skirt separation
- Drag skirt fabrication from MSL-style aluminum honeycomb with composite facesheets
- Heatshield and backshell made of solid carbon composite

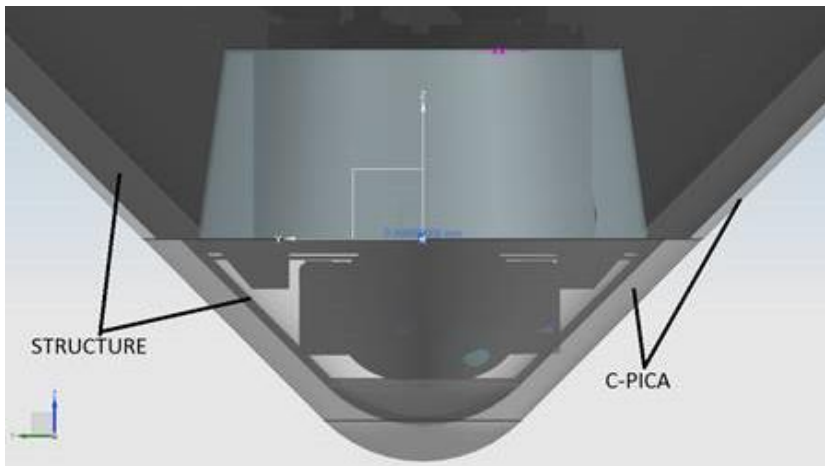


TPS Material Selection

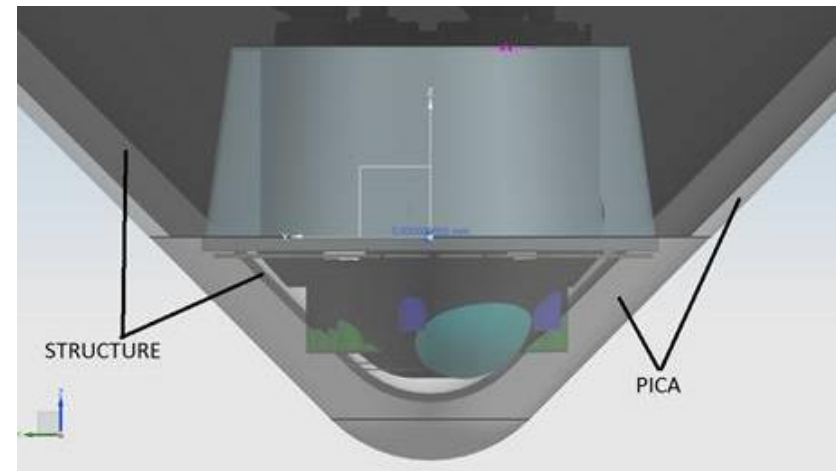


- Available volume in the nose of the spacecraft is important
 - Give space for components to keep the CG forward
 - Give space for the propulsion system to perform the PRM
- Required PICA thickness results in too little space, but C-PICA is much more flexible.
- Rough calculation: Every 1 cm increase in the spacecraft diameter requires ~8 cm increase in the drag skirt diameter to maintain the same beta ratio.
- To remain as compatible as possible with hosts, growing the drag skirt is not desirable, therefore we choose C-PICA.

C-PICA TPS



PICA TPS





Internal Flight System Configuration

